Ambulant Measurements of Physiological Status and Cognitive Performance during Sustained Operations

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ABSTRACT

Introduction: The physical and mental strain on combat soldiers is often high. They are exposed to a combination of factors that all contribute to the work load. These factors may include: sustained operations (up to 72 hours of continuous work), changing climatologically circumstances, different terrains (e.g. altitude), sleep deprivation, shift-work, nutritional shortage, and physical and chemical threats. Ambulant (real-time) monitoring of the strain to which soldiers are exposed may help prevent acute health problems (e.g. heat casualties) and overreaching / overtraining injuries; while also contributing to the prediction of the physical and cognitive performance of soldiers. The aim of this study was to gain insight into the level of cognitive performance of soldiers during sustained operations and to explore different methods to monitor the amount of strain (environmental, stress, work, sleep) soldiers experience during these operations. Methods: Seventeen soldiers who participated in the Air Mobile Brigade training were measured during week 1, 3 and 5 of the training course. Cognitive performance (memory, logical reasoning and vigilance) was tested 5 times each week. Ambient temperature, WBGT, humidity, rain fall and wind speed were continuously measured by a weather station. Body weight and fat percentage measurements were performed at the start of each week and at the end of the training course. The soldiers wore a system that measured heart rate, skin temperature and core temperature. GPS systems were used to monitor the walking and running distance and speed. Military instructors rated the physical and mental strain of the training course and the soldiers filled out questionnaires about vigour, affect, need for recovery, perceived exertion, mental effort and sleep. Results: Cognitive performance was significantly decreased as compared to baseline levels during the 3 test weeks. Vigilance and the more complex memory tasks proved to be the most sensitive to variations in cognitive performance. Heart rate measurements provide a good measure for energetic demands during the training course. Analyzing time spent in different heart rate zones allows for comparison between days. Measurements of skin and core temperature also give an idea of the physical strain of the training, but will be more valuable in real-time monitoring of health. GPS measurements are suitable to monitor the strain of walking and running activities, but measuring carried load would improve the accuracy the monitoring system. The questionnaires showed decreased vigour scores, increased need for recovery, increased mental effort, decreased sleep time and increased sleepiness during the tests weeks. Future studies will focus on the relationship between the different strain factors and cognitive and physical performance. Also, efforts will be made to optimize the measuring devices and to add measurements of sleep and energy expenditure by using accelerometers.

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14. ABSTRACT

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1. Introduction

The physical and mental strain on combat soldiers is often high. Soldiers have to deal not only with the high physical strain of their tasks, but also with the circumstances under which the work has to be performed. Soldiers are exposed to a combination of factors that all contribute to the work load. These factors may include: sustained operations (up to 72 hours of continuous work), changing climatologically circumstances, different terrains (e.g., altitude), sleep deprivation, shift-work, nutritional shortage, and physical and chemical threats.

Sustained operations and high levels of physical and mental strain do not only occur in real combat situations, but also in training courses. Although there are no hostile threats in training courses, factors such as physical strain (the actual work load is often higher in training situations), sleep deprivations, weather influences and mental stress (mental exercises, exams) play an important role.

Physical and cognitive performance levels tend to decrease during sustained operations [1, 2]. Also, during extreme circumstances, the soldiers' health can be at risk (short term and long term consequences).

There is a growing interest in monitoring and predicting soldiers' performance. Ambulant (real-time) monitoring of the strain to which soldiers are exposed may lead to:

- prevention of acute health problems (e.g. heat casualties)
- prevention of overreaching / overtraining injuries of soldiers by using the data for adjustment of training load or work load
- prediction models for physical and cognitive performance levels of soldiers

The Netherlands Defence Organization initiated a 4-year Defence Research Program in 2008. This Program, called 'Military Performance and Health Monitoring', aims at developing knowledge on physical and cognitive sustainability during military operations in extreme environments. In return, this knowledge will be used to develop (real-time) performance and health monitoring systems for individual operational readiness.

This report describes the first field study conducted in the Research Program. The aim of this study was to gain insight into the level of cognitive performance of soldiers during sustained operations and to explore different methods to monitor the amount of strain (environmental, stress, work, sleep) soldiers experience during these operations.

2. Methods

2.1 Design of the study

subjects

Soldiers (20 – 43 year old; mean ± sd: 29.1 ± 5.3) who qualified for the Air Mobile Brigade training course took part in this study (n=17). Qualification took place two weeks before the start of the training course. In this qualification, soldiers were tested on their physical and cognitive status by military instructors. The soldiers were informed about the study and the measurements in advance and all gave their written informed consent.

design

The Air Mobile Brigade training course started on the 25th of August 2008 and lasted until the 10th of October 2008. Baseline measurements took place on August 22nd 2008. During this day the soldiers were informed about the purpose of the measurements; received information about all measurements; got acquainted with the monitoring systems; filled out questionnaires; practiced the tasks measuring cognition three times and were free to ask questions.

The first (25 – 29 August), third (8 – 12 September) and fifth (22 – 26 September) week of the training course the soldiers were trained in the field. It was during these weeks that the soldiers had to perform tasks to measure their cognition five times: on Monday, Wednesday and Friday morning and in the afternoon on Wednesday and Friday. During the days in which the cognitive testing took place, the physiological parameters of the soldiers were continuously measured. During the remaining weeks (week two, four, six and seven), physical activity was less pronounced and the soldiers were not measured. The soldiers went home on weekends. The trainings sessions were held on different locations in the Netherlands.

2.2 Climate measurements

Climate circumstances were measured during the test weeks using two devices. A Wet Bulb Globe Temperature (WBGT) was used to determine temperature (Celsius), humidity (%) and wind speed (m/s). Temperature was calculated using the following formula:

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_d$$

Where

- T_w = natural wet-bulb temperature (humidity)
- T_g = globe thermometer temperature (solar radiation)
- T_d = dry-bulb temperature (normal air temperature)

A weather station (Oregon scientific WMR-200, Oregon Sciencific Inc., Portland, Oregon, USA) was used to measure temperature (Celsius), relative humidity (%), wind speed (m/s) and rainfall (mm).

2.3 Cognitive performance

To assess cognitive performance, three tasks were performed. Total completion time was about 20 minutes. The tasks were performed on a laptop (MSI U100, Taipei Hsien, Taiwan).

2.3.1 Working memory

Working memory was tested using the N-back task [3, 4]. Three levels of difficulty (0-back, 1-back, 2-back) were included. The total duration of the test was 5 minutes. Reaction time and accuracy were recorded.

2.3.2 Logical reasoning

Reasoning and planning was tested using the Tower of Hanoi test (modified version of http://step.psy.cmu.edu/scripts-plus/ TOHx). The test consisted of seven patterns that needed to be solved ranging from 2-step problems to 7-step problems. On average, the time needed to execute the task was 5 minutes. The time taken to solve the tasks and the number of illegal moves were recorded.

2.3.3 Vigilance

Vigilance was tested using the VigTrack test (Vigilance and Tracking test, [5]). The time of the test was set at 5 minutes. Deviation from the target, reaction time, illegal responses, and missed responses were recorded.

2.4 Physiological measurements

2.4.1 Anthropometry

Weight measurements were performed with a Seca 770 scale (Hamburg, Germany) and fat percentage was measured with a caliper (Servier), according to the method of Durnin en Womersley [6].

2.4.2 Heart rate, skin and core temperature

A number of physiological parameters were measured using Hidalgo Equivital™ Life Monitors (Hidalgo Limited, Cambridge, UK). These systems are worn at the chest and measure: heart rate, skin temperature and core temperature with the use of a Jonah™ core temperature sensor (JonahTM Ingestible Core Temperature Capsule, Mini Mitter Co., Bend, Oregon).

Summary data was calculated every 15 seconds and used for further analysis. Data was inspected and measurement errors were excluded from the data using Matlab (The MathWorks, Natick, USA). Heart rate was resampled to a frequency of 1/60 Hz. The quality of the signal was rated a ‘1’ for a good signal and a ‘0’ for a poor signal. The signal was rated good when

- the Heart rate quality signal (provided by Hidalgo) was ≥ 70%
- the Heart rate was between 30 and 200 beats per minute

Heart rate was recalculated into percentage Heart Rate Reserve with the following equation, developed by Karvonen et al. [7]:

$$\%HRR = \frac{(HR_{exercise} - HR_{rest})}{HR_{\max} - HR_{rest}} * 100\%$$

The resting HR (HR_{rest}) of the soldiers was determined over the test period. The lowest HR of good quality averaged over 60 seconds of the whole test period was used as resting HR. The maximum HR (HR_{max}) was determined by finding the highest HR with good quality averaged over 60 seconds of the whole test period.

HRR values were recoded into different intensity zones. As a measure for physical strain, time spent in the different zones was used. The following intensity zones were used:

Zone 1: 0-50% HRR	(low activity level)
Zone 2: 50-75% HRR	(moderate activity level, mainly aerobic)
Zone 3: 75-100% HRR	(heavy exercise, also anaerobic component)

2.5 Distance and Speed

As a measure for the amount and intensity of movement, walking or running distance and the speed of the movements were recorded. A GPS system (SPi-Elite, GPsports Australia) was mounted on the soldiers' backpack. The system measured continuously during the training weeks. Walking or running speed is presented as amount of meters per day per speed zone. Table 1 shows the defined zones:

Table 1: Walking or running speed belonging to zones 0 to 6

Zone	Speed (km/h)
0 (no movement)	0 – 1
1	1 – 2
2	2 – 4
3	4 – 6
4	6 – 8
5	8 – 13
6 (not walking/running)	> 13

2.6 Subjective measurements

2.6.1 Instructors ratings

During the training course, the instructors were asked to subjectively rate the physical and mental strain of the training course during the measurement weeks on a scale from 1 'very heavy' to 5 'light strain/ rest'.

2.6.2 Questionnaires

Questionnaires were filled out (i) during the baseline measurement, (ii) during all test moments during the training course and (iii) at the end of the training. The following questionnaires were used:

- GVA (Global Vigour and Affect Scale)
- HBV (Dutch Need for Recovery Questionnaire)
- RPE (Rate of Perceived Exertion)
- RSME (Rating Scale Mental Effort)
- Sleep diary
- SSS (Stanford Sleepiness Scale)

<u>GVA</u>

The Global Vigour and Affect Scale (GVA) was used to detect subjective changes in vigour (GV) and affect (GA) [8]. The scores give an indication of the changes in mood and activation / alertness of the soldiers over time. The scale contains eight items, ranging from 0 ('not at all') to 100 ('very much'). Four items are used for the vigour score: alertness, sleepiness, effort and weariness. The other four items (happiness, calmness, sadness and tenseness) are used to determine the affect score.

<u>HBV</u>

The Dutch Need for Recovery Questionnaire (HBV, [9]) rates the extent to which soldiers need time to recover. The questionnaire gives insight in the subjective strain of the training course. The questionnaire consists of 11 yes/no items.

<u>RPE</u>

The Rate of Perceived Exertion (RPE, [10]) rates the amount of perceived exertion using one question. Soldiers rate how exerted they are. The answer ranges from 6 ('no effort') to 20 ('maximal effort').

RSME

The Rating Scale Mental Effort (RSME, [11]) rates the perceived mental effort with one question. Soldiers have to indicate how much effort it took them to complete the tasks during the training course. Answers range from 2 (‘no effort’) to 112 (‘enormously effortful’).

Sleep diary

A sleep diary was filled out by the soldiers to get insight in the sleep-wake rhythm. The total sleep time, quality of the sleep (ranging from 1 (‘very poor quality’) to 4 (‘very good quality’)), time needed to fall asleep and the sleep efficiency were used for analysis. The diary consists of 10 questions.

SSS

The Stanford Sleepiness Scale (SSS, [12]) rates the alertness of the soldiers. It is a quick way to get insight into the sleepiness of the soldiers during the training course. The SSS consists of one question with a 7-point scale, ranging from 1 (‘feeling active and vital; wide awake’) to 7 (‘almost in reverie; sleep onset soon; lost struggle to remain awake’).

2.7 Statistical analysis

A within-subjects repeated-measures ANOVA was used to analyze the data over the three weeks for the soldiers who completed the training course, using Statistica 7.0 software (Statsoft, Tulsa, USA). When the analyses revealed a significant difference, a Tukey Honest Significant Difference (HSD) test was used for post hoc comparisons. The level of statistical significance was set at $p = 0.05$.

3. Results

During the training course, 8 of the 17 soldiers dropped out because of medical reasons (n=5) or negative decision of the instructors (n=3). For comparisons over time, data of the remaining 9 soldiers who completed the training course is presented.

3.1 Weather measurements

During the training course, weather conditions were measured to assess the environmental strains. As an example, figures 1a and 1b show the measured temperatures, humidity, rainfall and wind speed over the days during the first training week.

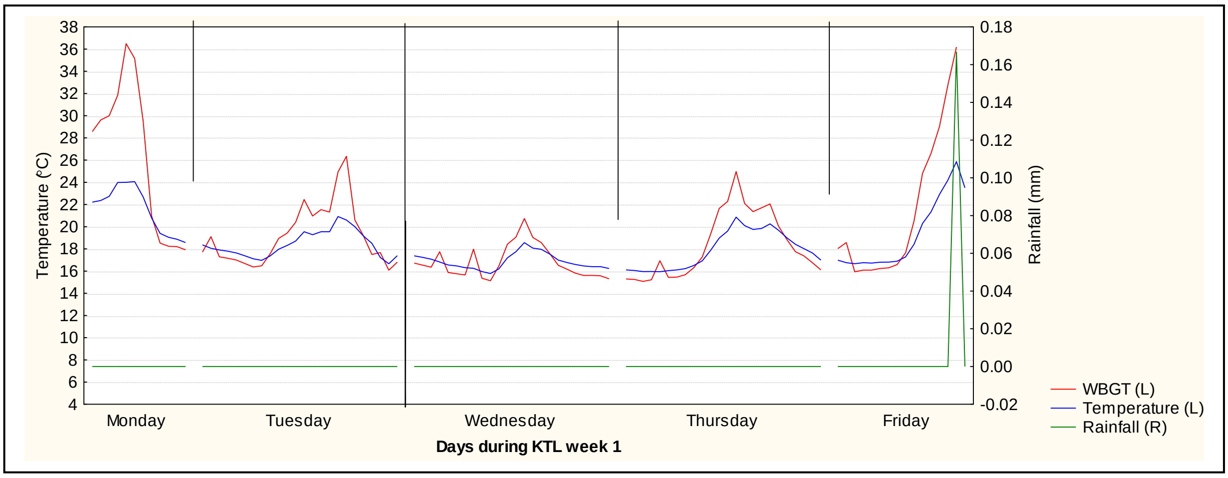


Figure 1a: Temperature and rainfall during week 1

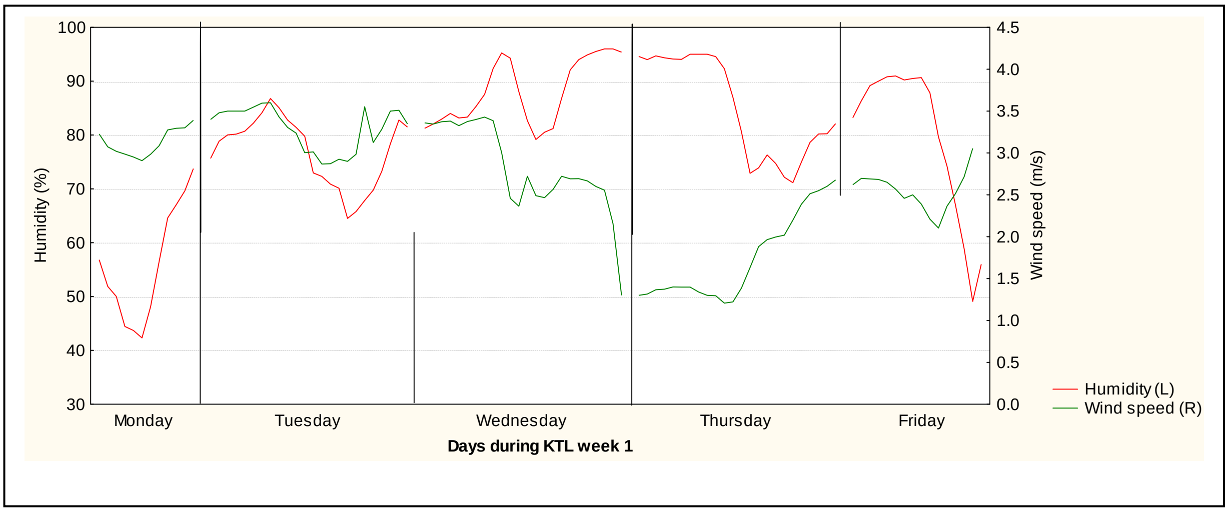


Figure 1b: Humidity and wind speed during week 1

No extreme temperatures, wind speeds or rainfall were measured during the weeks, see table 2 where average weather measurements are presented. Unfortunately, no temperature, rainfall and humidity were measured during week 2. Also, some data is missing due to transportation to other locations. There were no opportunities to measure the weather when travelling.

Table 2: Minimal, maximal and average temperatures, rain, wind and humidity during the training course

Weather condiotions	Week 1	Week 2	Week3
	Min – max; Mean ± sd	Min – max; Mean ± sd	Min – max; Mean ± sd
WBGT	15.1 – 36.5; 19.6 ± 5.0	9.8 – 31.5; 18.5 ± 5.3	5.1 – 26.2; 13.4 ± 4.9
Temperature	15.8 – 25.9; 18.4 ± 2.3	-	6.7 – 24.5; 13.8 ± 3.7
Rainfall	0 – 3.6 ; 0 ± 0	-	0 – 0.1 ; 0 ± 0
Wind Speed	1.2 – 3.6 ; 2.7 ± 0.7	0.8 – 3.6 ; 2.3 ± 0.8	2.3 – 4 ; 3.4 ± 0.5
Humidity	42.3 – 96 ; 79.5 ± 13.3	-	35.0 – 98 ; 76.2 ± 16.7

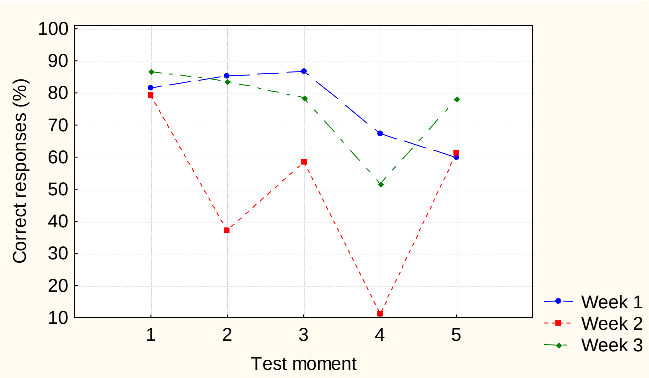
3.2 Cognitive performance

Cognitive performance was measured 5 times per week:

1 – Monday morning
2 – Wednesday morning
3 – Wednesday afternoon
4 – Friday morning
5 – Friday afternoon

3.2.1 Working memory (N-back task)

The Two-Back task was more sensitive to changes in cognitive performance than the Zero-Back and the One-Back tasks, meaning that higher difficulty levels led to greater decreases in soldiers' performance. The Two-Back showed a significant ($p < 0.01$) lower percentage of correct Target responses during the Wednesday- and Friday morning in week 2 (figure 2a). On Friday morning in week 3, soldiers scored significantly worse compared to the other test moments that week ($p < 0.05$). The Two-Back showed significant differences in reaction time between the weeks and the test moments [$F(8,64)=2.16$, $p < 0.05$]. The Friday morning test resulted in significant lower reaction time than the tests on Wednesday morning and Friday afternoon ($p < 0.05$), shown in figure 2b.



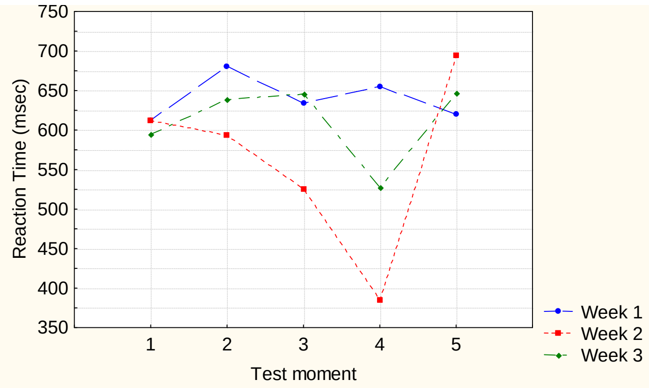


Figure 2a: % Correct Target responses Two-Back

Figure 2b: Reaction Time Target Two-Back

3.2.2 Logical reasoning (Tower of Hanoi)

The completion time in week 2 differed significantly from the completion time in week 1 and 3 ($p < 0.01$). The Wednesday morning results and the Friday morning results revealed that the soldiers needed significant longer completion times ($p < 0.01$) compared to all other test moments in week 1, 2 and 3 (figure 3).

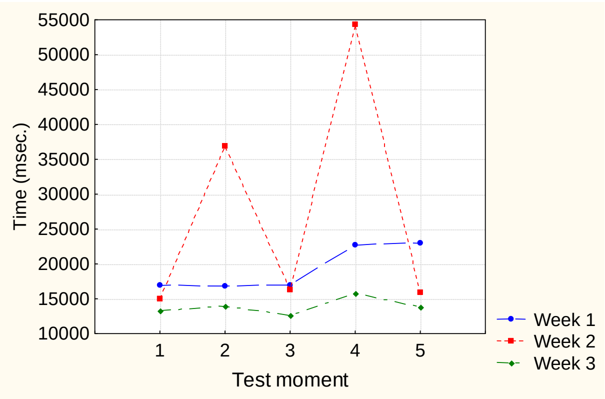


Figure 3: Mean completion time of the Tower of Hanoi

3.2.3 Alertness/ vigilance (VigTrack)

The VigTrack task measuring alertness and vigilance showed significant Tracking differences between the weeks and the measurement moments [$F(8,64)=9.93$, $p< 0.01$]. The results in week 2 (figure 4) revealed significant higher deviations from the Target compared to the results in week 1 and 3 ($p< 0.01$).

During the Friday afternoon in week 1, soldiers had a significantly higher mean deviation from the Target during the Tracking task compared to the test moments 1 to 3 during that same week ($p< 0.01$). Week 2 showed a lot of variation in results. Especially, the measurements on Wednesday morning and Friday morning revealed high deviations from the target and thus worse vigilance. During these two test moments in week 2, soldiers showed significantly different results compared to the same test moments in week 1 and 3 ($p< 0.01$). Wednesday afternoon in week 2 resulted in significantly worse tracking performances compared to the same test moment in week 1 and 3 ($p< 0.05$).

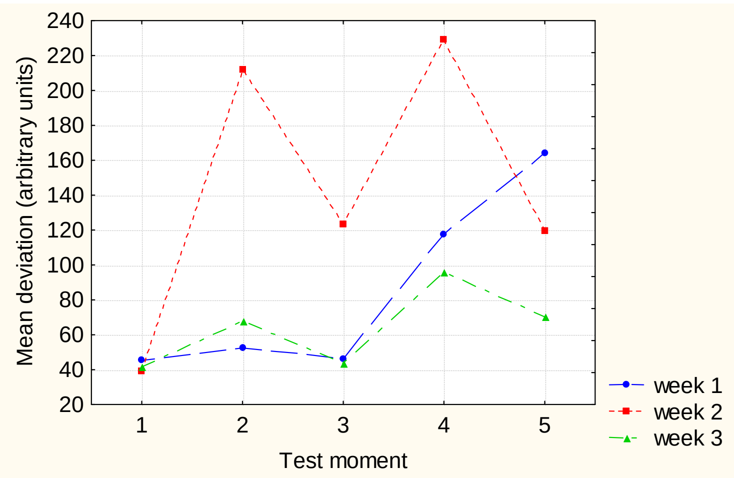


Figure 4: Mean deviation from the Target during the VigTrack

The soldiers showed significant differences in vigilance as well. Reaction times were significantly different between the weeks and between the test moments [$F(8,64)=6.47$, $p< 0.01$] (figure 5a). Like the tracking task, there was a significant difference in reaction time during the second week compared to the other weeks ($p< 0.01$).

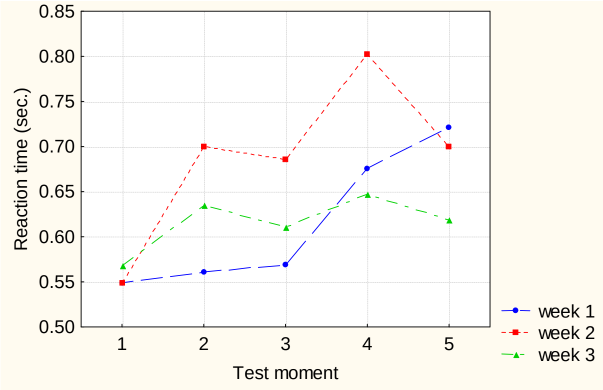


Figure 5a: Reaction times on the stimulus during VigTrack

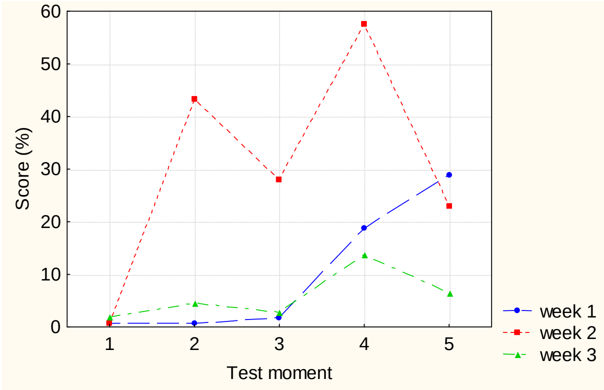


Figure 5b: Percentage of missed stimuli during the the VigTrack

The changes in reaction time showed almost the same pattern as the percentage of missed stimuli (figure 5b). The results of the tracking task of the VigTrack and the percentage missed stimuli were even more alike.

3.3 Physiological measurements

3.3.1 Anthropometry

The soldiers who completed the training course showed a significant decrease in weight over time [F (3,24)=4.01, p<0.05]. The post hoc test revealed that the weight measured at the end of the training course was significantly lower than the weight at the start of the course. Their weight reduced by almost two kilograms (table 3).

The soldiers showed a significant decrease in fat percentage over time [F(3,24)=10.42, p<0.01]. Post hoc analysis showed that the fat percentage during week 3 and during the end measurement was significantly lower than the fat percentage at the start (see table 3).

Table 3: Weight and fat percentage of soldiers who completed the training course (n=9)

	Weight (kilograms)	**Fat percentage (%)**
	Mean ± sd	Mean ± sd
Start week 1	85.48 ± 2.81	15.86 ± 1.42
Start week 2	84.84 ± 2.74	14.92 ± 1.35
Start week 3	84.69 ± 2.52	14.16 ± 1.48
End of course	83.71 ± 2.31	13.68 ± 1.28

3.3.2 Physiology

Heart rate

Figure 6 shows an example of HRR values of one of the subjects during the training course. Measurements started Monday, Wednesday and Friday morning and lasted approximately 24 hours for the Monday and Wednesday measurements and until Friday afternoon for the Friday measurements. On Wednesday afternoon in week 2, the measurement devices were removed for a few hours, because of safety reasons. The colors in the graphs represent the different heart rate zones (green: 0-50% HRR, orange 50-75% HRR and red 75-100% HRR), as defined in section 2.4.2.

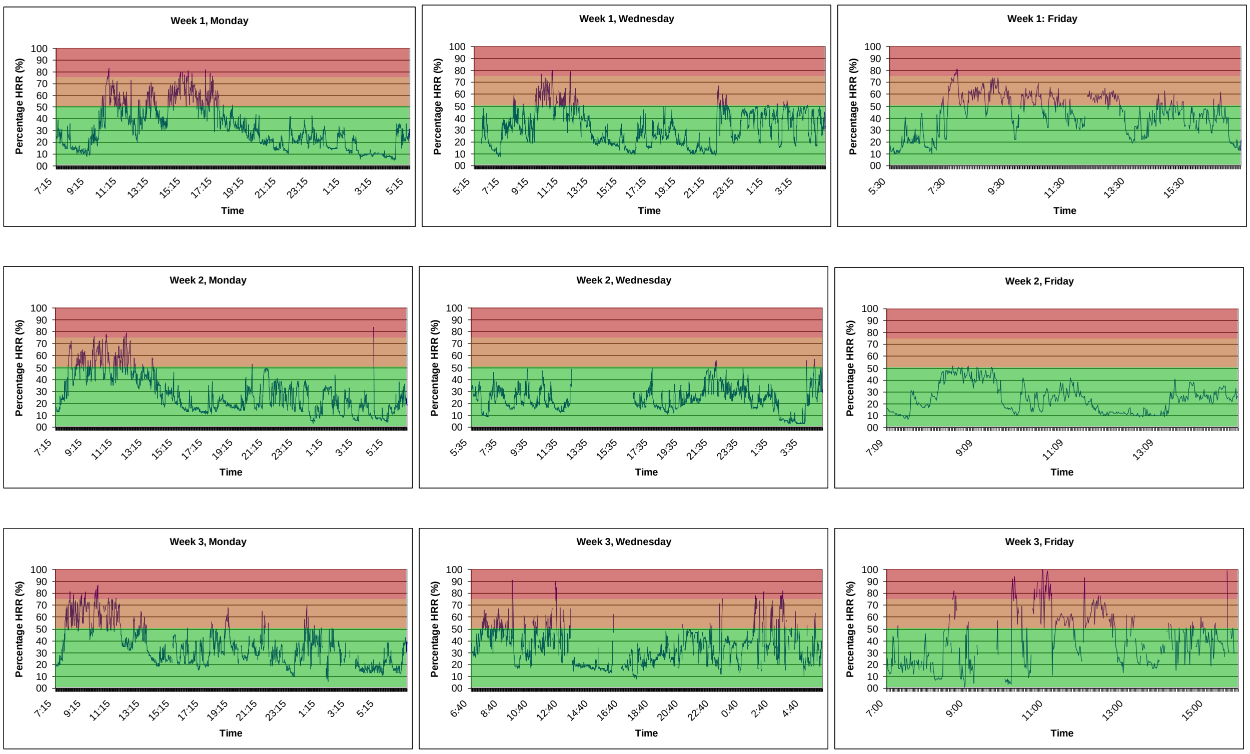


Figure 6: HRR values of one of the subjects

The mean HRR values for the group per day are presented in table 4.

Table 4: Mean HRR (in %HRR) per day (n=9)

	Week 1			Week 2			Week 3		
	mon	wed	fri	mon	wed	fri	mon	wed	Fri
Mean	36	35	50	32	26	30	40	36	43
Sd	22	18	19	19	13	14	20	15	23
Mean time recorded (minutes)	1223	1152	560	1226	1031	456	1246	1073	482

For a better understanding of the energetic strain, figure 7 presents the amount of time spent in the different HRR zones. Week 1 and week 3 reflect higher physical activity levels as compared to week 2.

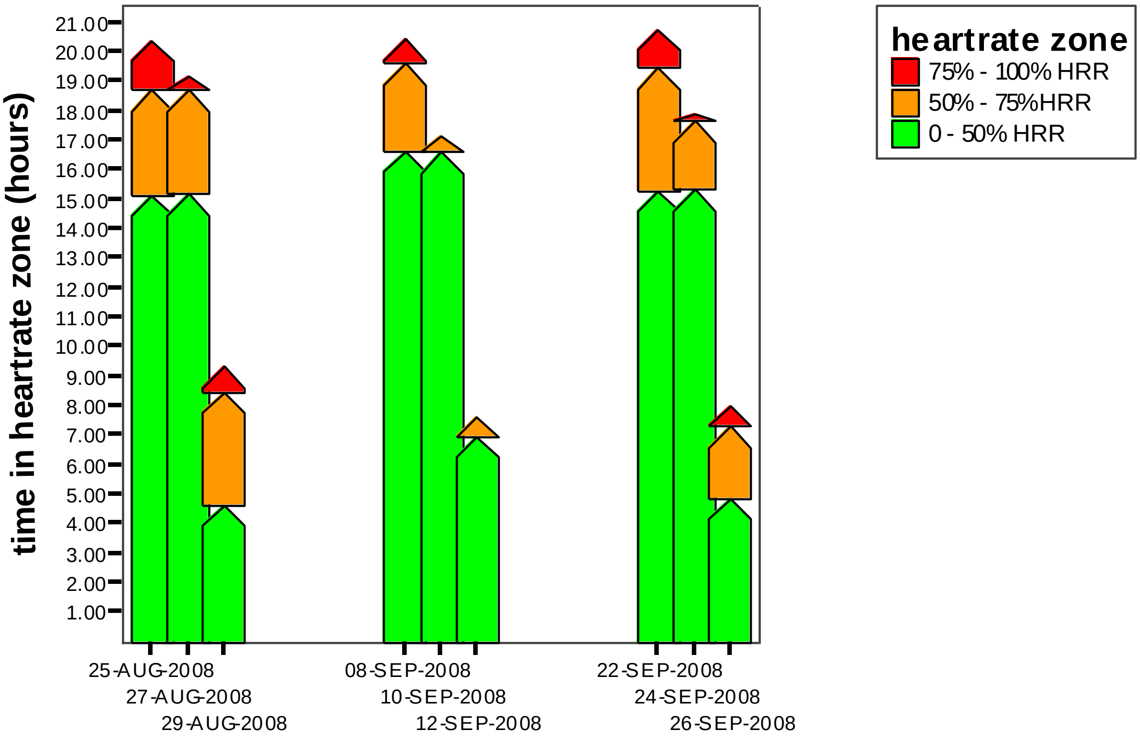


Figure 7: Time spent in the defined HRR zones (n=9)

Core and skin Temperature

Core temperature was measured by a Jonah™ core temperature sensor. Each night (between 11PM and 4AM) prior to the measurement day, soldiers swallowed the pill. Highest core temperatures were measured during the first week on Monday and Friday. During those days, core temperature reached values over 38.5°C averaged per hour. Lowest temperatures were measured early in the morning on Tuesday during all three weeks, reflecting the resting period of the soldiers. During the other days of the weeks the resting periods were shorter and more spread over the day. Skin temperature was measured by the Hidalgo belt that was worn around the chest. The skin temperature in figure 8 represents chest temperature.

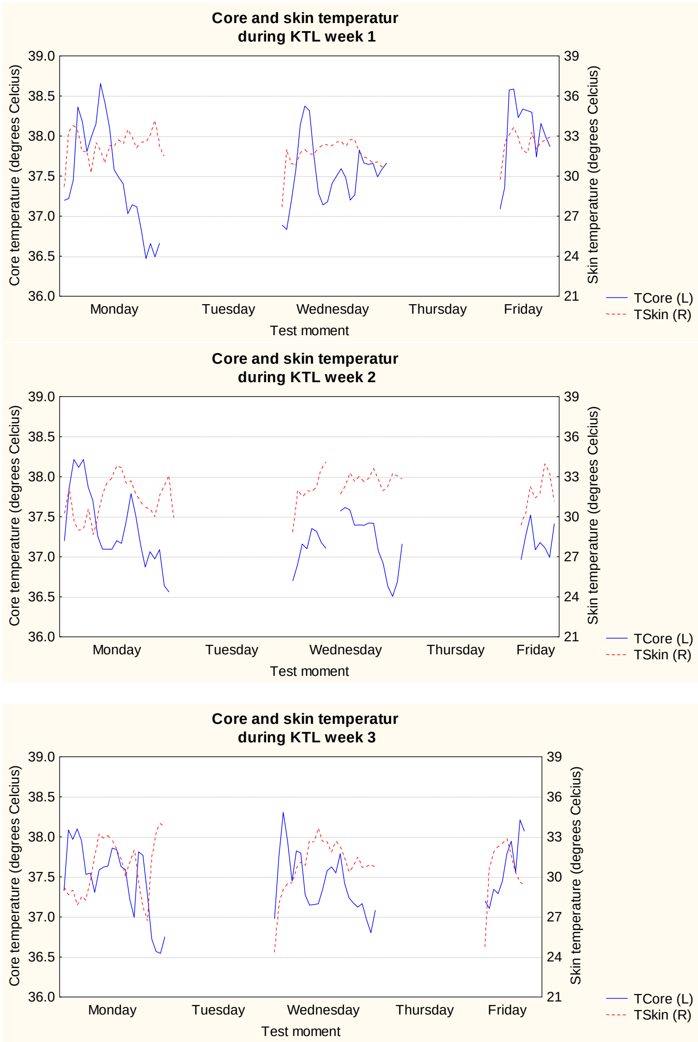


Figure 8: Combined core and skin temperature (n=9)

3.4 Distance and speed

Figure 9 shows the walking and running distances per day as measured by the GPS system. Distances are presented per speed zone.

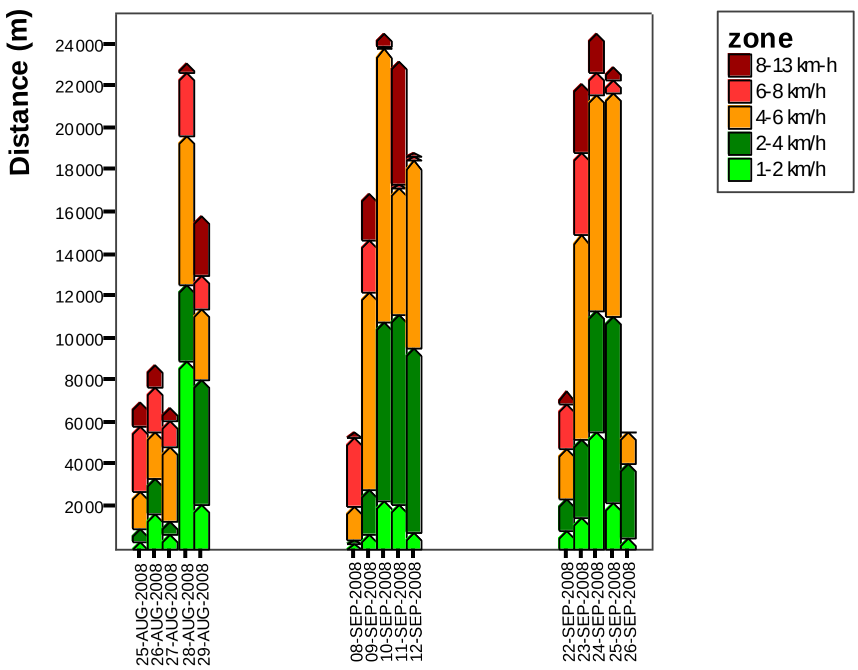


Figure 9: Distances walked in the different speed zones

3.5.1 Instructors ratings

The instructors of the Air Mobile Brigade training course were asked to rate the physical and mental strain on the soldiers during the three test weeks (figures 10a, 10b and 10c). A high score indicates that the strain was light, while a low score indicates high strains. Scores were given per half hour for each day. When looking at the figures, the Tuesday during week 1 was rated by the instructors as a very light day for the soldiers while the Friday during that same week asked a lot more from the soldiers both physically and mentally. When comparing the three weeks, week 3 seems to be the lightest week with some strain on Monday. Interestingly, there is hardly any moment where the soldiers face either physical or mental strain. Rather, physical and mental strains are generally experienced concurrently.

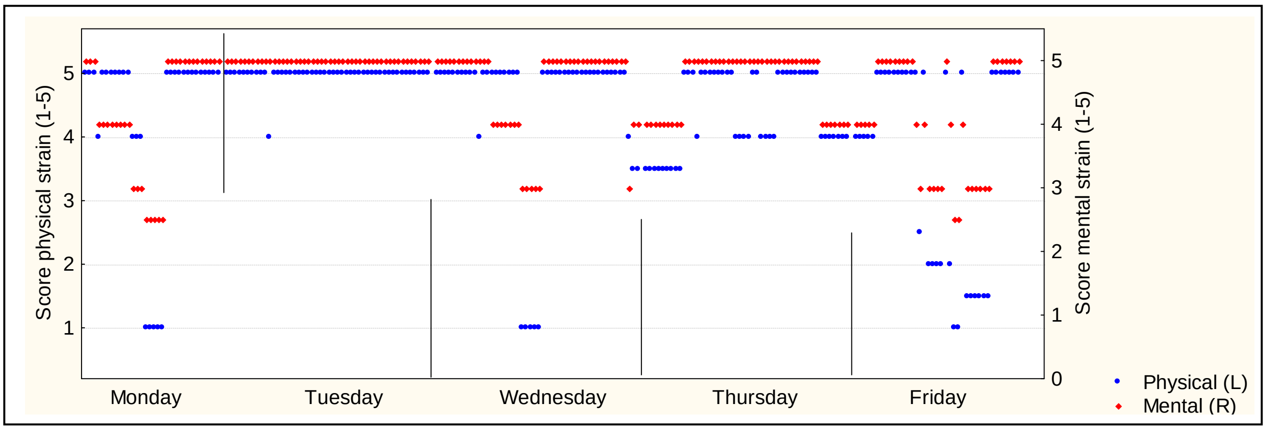


Figure 10a: Physical and mental strain ratings of the instructors during week 1

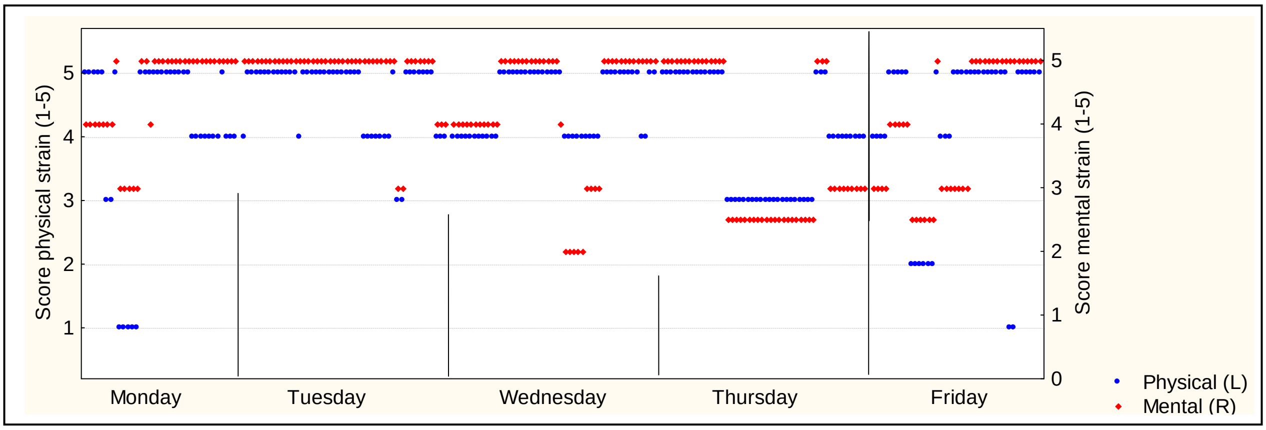


Figure 10b: Physical and mental strain ratings of the instructors during week 2

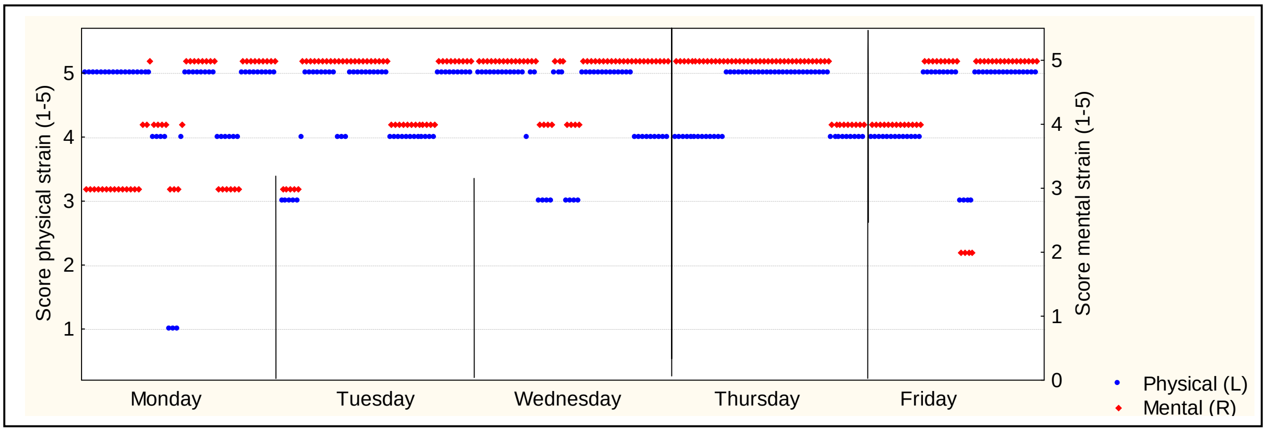


Figure 10c: Physical and mental strain ratings of the instructors during week 3

3.5.2 Questionnaires

Global Vigour and Affect (GVA)

Vigour scores during the course showed significant differences between the weeks and within the weeks [$F(8,64)=5.90$, $p< 0.01$]. Scores on Global Vigour (vigour/ liveliness) were significantly lower during week 2 compared to week 1 and 3 ($p< 0.01$) (figure 11a). The highest vigour scores were seen during the first test moment on Monday morning. From the second test moment on, the soldiers scored significantly lower on vigour during all three weeks.

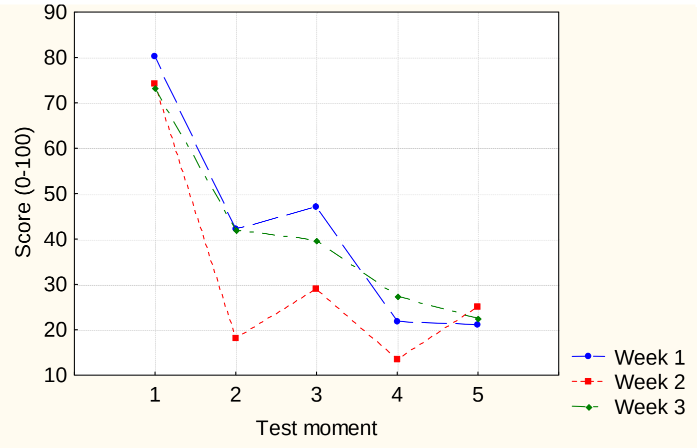


Figure 11a: Global Vigour on the GVA

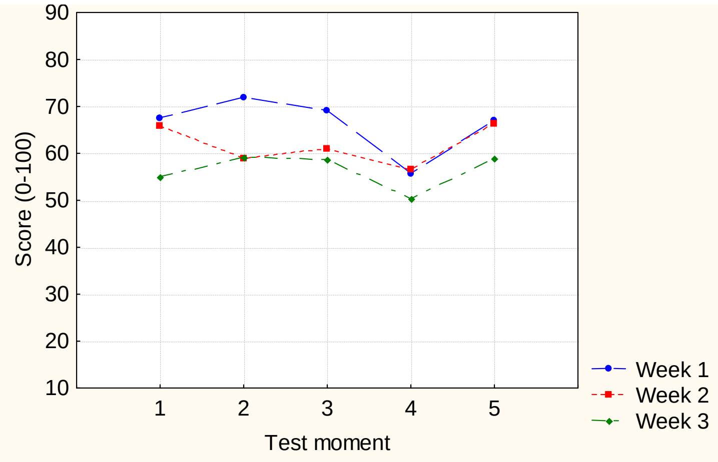


Figure 11b: Global Affect on the GVA

The GA (affect) scores were significantly lower in week 3 than during week 1 and 2 [$F(2,16)=15.84$, $p< 0.01$] (figure 11b). At the Friday morning test, the soldiers rated significantly lower affect scores compared to the other measurement moments ($p< 0.05$). No other significant differences were found in affect.

Dutch Need for Recovery Questionnaire (HBV)

There were no significant differences between the weeks when questioning the soldiers about their need for recovery. It was only the first day of the week that the soldiers reported significant lower [$F(4, 32) =25.81$, $p<0.01$] needs for recovery (figure 12).

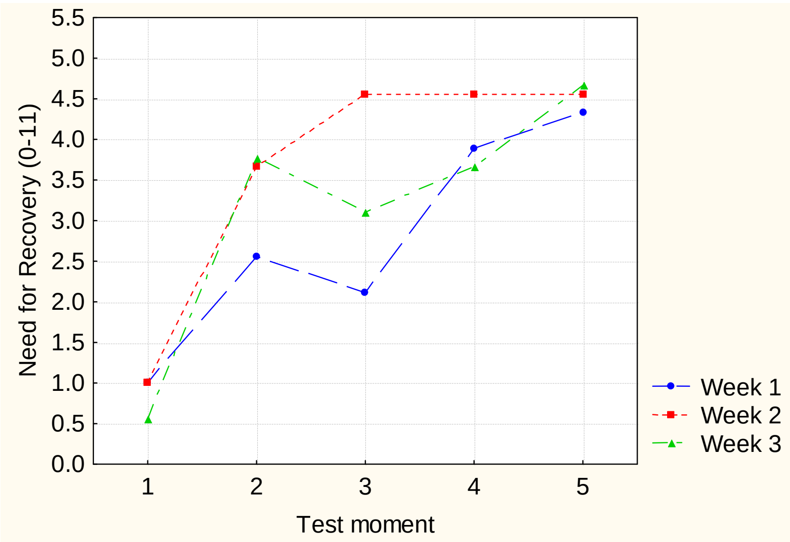


Figure 12: Need for recovery

Rate of Perceived Exertion (RPE)

The rate of perceived exertion was rated significantly lower during the first day of week 1 compared to week 2 and 3 [$F(8,64)=6.29$, $p< 0.01$] (figure 13). During this first test moment soldiers rated their

exertion with a score little lower than 12, meaning ‘light’ effort; while the scores during the rest of the week and week 2 and 3 all were between 16.5 and 18.5, corresponding to ‘very heavy’.

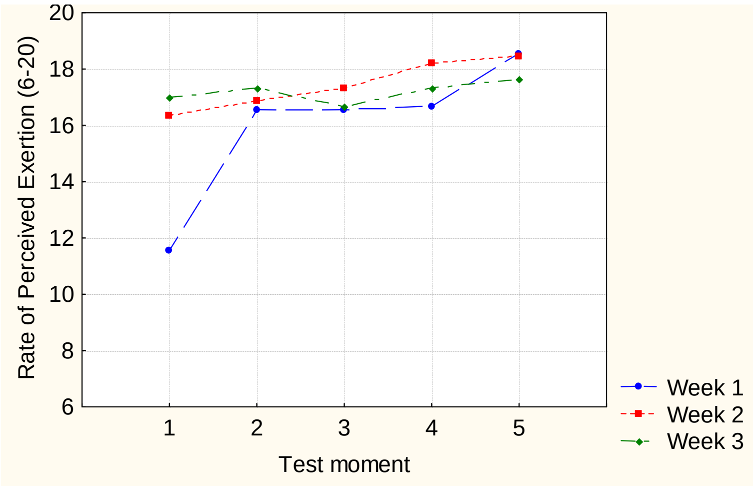


Figure 13: Rate of Perceived Exertion

Rating Scale Mental Effort (RSME)

Soldiers rated their mental effort during week 1 significantly lower when compared to week 2 and 3 [$F(2,16)=15.86$, $p< 0.01$] (figure 14). It was the Monday morning test during week 1 that was rated significantly lower on mental effort by the soldiers compared to all other measurement moments ($p< 0.01$).

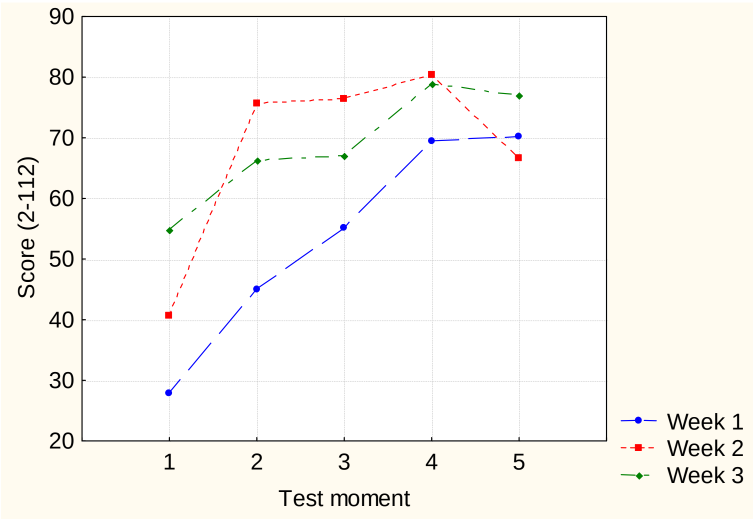


Figure 14: Mental effort measured with the RSME

Sleep diary

Total sleep time was assessed on Monday, Wednesday and Friday. The results show the amount of sleep over the last 24 hours prior to the test moment (figure 15).

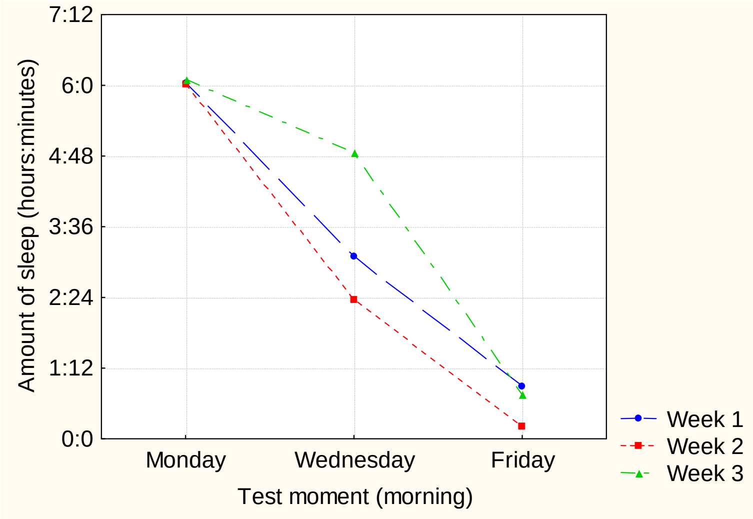


Figure 15: Total sleep time

The amount of sleep of the soldiers was significantly less during week 2 compared to week 3 [*F* (2,16)=4.42, p<0.05]. Not only did the amount of sleep differ between the weeks but also within the weeks significant differences in total sleep time were found. The amount of sleep decreased significantly from the first test moment on Monday till the last test moment on Friday [*F* (2,16)=123.20, p<0.01]. At the start of the test weeks, all soldiers slept around six hours, while halfway during the week the amount of sleep was reduced to 2.5 to almost 5 hours. At the end of the week, the amount of sleep reduced to no more than 1 hour of sleep.

Stanford Sleepiness Scale (SSS)

The results showed significant differences between the weeks and within the weeks [*F* (8,64=4.61, p<0.01]. The sleepiness of the soldiers was significantly higher during week 2 compared to weeks 1 and 3. No significant difference was observed between week 1 and 3. The rates at the test moments within the weeks demonstrate that the soldiers became significantly sleepier over time (figure 16).

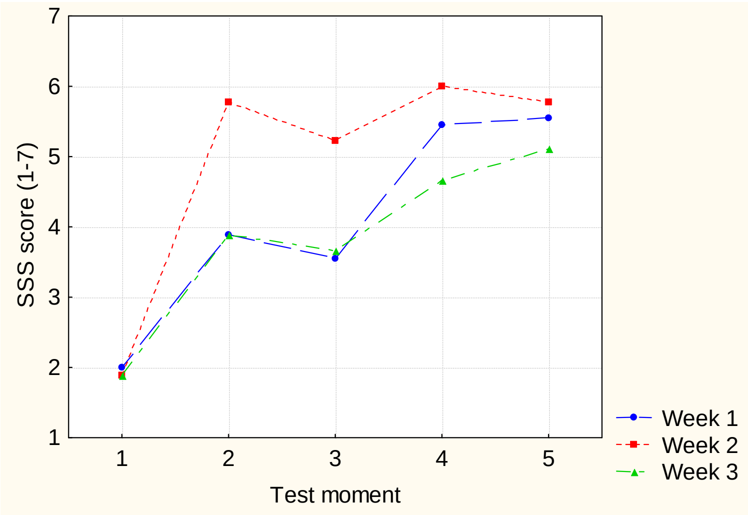


Figure 16: SSS score

4. Discussion

The first goal of this study was to gain insight in the cognitive performance levels of soldiers during sustained operations. Does high physical and mental strain, in combination with sleep deprivation, lead to decreased performance on cognitive tasks? In this study, three cognitive tests were used that measure memory, logical reasoning and vigilance. The results show a significant decrease in cognitive performance as compared to baseline levels during the 3 weeks, which can be regarded as 3 separate sustained operations. The VigTrack test appeared to be the most sensitive test to detect changes in cognitive performance levels. In the memory test, the more complex test (Two-Back) was more sensitive to changes than the relatively simple tests (Zero-Back and One-Back). Scores for logical reasoning (Tower of Hanoi) did not vary a lot.

The decreased cognitive performance levels correspond with the findings of Lieberman et al. [13]. These authors also found a decrease in self-reported vigour and an increase in fatigue, depression, anger and confusion. In the present study, global vigour scores decreased strongly during the 3 weeks. Also, a significant increase in ‘need for recovery’, ‘mental effort’ and ‘sleepiness’ was shown. A new multi-component assessment model for monitoring training distress is proposed by Main and Grove [14]. This model combines measures of mood disturbance with measures of perceived stress and symptom intensity. This new model looks promising for future field studies.

The second goal of this study was to explore different methods for monitoring the amount of strain soldiers experience during sustained operations. Because the focus of this study is on the applicability of different devices in a military setting, the absolute values of data measured in the study will not be discussed in this paper. The data will be used, however, in combination with data from other field studies, to investigate relationships between the different strain parameters and physical and cognitive performance. Also, the data are useful for the military command as a first objective measure of cognitive performance and strain during their training course.

Measuring ambient temperature, wind speed, relative humidity and radiation in a field setting is possible using the weather stations, although improvements can be achieved by using smaller sensors that can be mounted on the soldiers’ backpack. Furthermore, data of different sensors can be transformed to indices like Wind Chill [15] and Heat Index / humidex [16] as a measure for combined effects.

Heart rate is an important and easy-to-measure parameter for energetic demands. The use of heart rate reserve values is well accepted as is the use of different heart rate zones, although different zones are used depending on the application. Heart rate zones used for training athletes will differentiate in the higher levels of %HRR. For measuring work load, also the lower heart rates should be taken into account. One of the methods to convert heart rate data to one measure of training load per unit of time is the TRIMP (TRaining IMPulse) score [17]. Here also, for the purpose of monitoring workload of soldiers, a combined score has to cover the whole range of work intensities. To our knowledge, only one study used the TRIMP score to quantify workload [18]. One of our future goals is to modify the TRIMP method for measuring (energetic) workload of soldiers.

Measuring skin temperature and core temperature works well with the Hidalgo system. Core temperature also gives an indication of the work load. The most important application for core temperature lies in real-time monitoring, where it serves as an early warning for heat stress. A useful measure for this purpose is the Physical Strain Index (PSI) developed by Moran et al. [19]. The PSI is calculated from heart rate and core temperature. The PSI is not presented in this field study, but will be used in future research.

GPS systems are suitable to monitor walking or running distance and speed. Only in heavily wooded areas, the quality of the signals is poor and will lead to errors. The Netherlands Army is developing a system that combines GPS data with data of an accelerometer to be able to correct for these errors.

Apart from distances and speed, load carried on the body is an important factor in the total workload of soldiers. Continuous measurement of total body weight by means of pressure sensors in the shoe will allow a more accurate measurement of the total workload. A project has started for the development of a device to measure bodyweight during operations. In analogy with the TRIMP score, total strain of walking and running might be expressed in one index calculated from distance, speed en body load.

Finally, accelerometers have great potential in ambulant monitoring. Applications are quantifying sleep, quantifying activity and estimating energy expenditure. The second field study of the research program will focus on the validity of different accelerometers towards energy expenditure, measured by the doubly labelled water technique. In a laboratory study, the validity of accelerometers predicting sleep quantity will be studied.

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